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OFFICIAL PROCEEDINGS
Meeting of October, 1922.

Volume XXI.
No. . . 7.

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INCORPORATED OCTOBER 1913

Canadian Railway Club

MONTREAL

CONTENTS.

REPORT OF OCTOBER MEETING

and

Paper and Discussion on

"SOME ELEMENTS OF ECONOMY IN AIR COMPRESSION"

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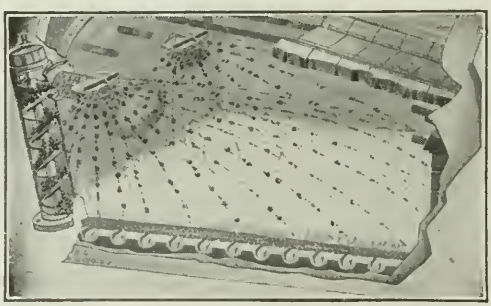

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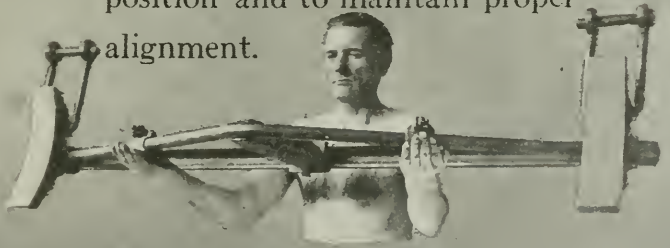

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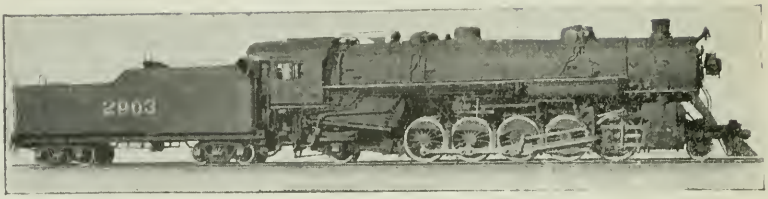

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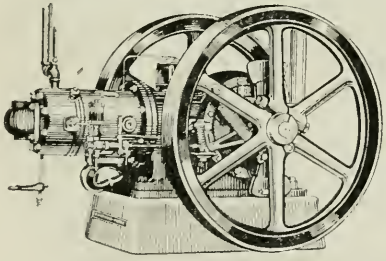

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PROCEEDINGS OF THE CANADIAN RAILWAY CLUB

Windsor Hotel, Montreal,
October 10th, 1922.

Chairman: (Mr. G. M. Wilson).

I will now call this meeting to order, and would ask you all to kindly fill in the attendance cards.

MEMBERS PRESENT

Wilson, G. M.
Atkinson, F.
Bailey, E. W.
Barrett, C. W.
Barton, A.
Barton, Master A.
Beaulieu, D.
Bell, H. C.
Bermingham, T. C.
Bird, H.
Birkett, L. H.
Boyer, G.
Brandon, J. B.
Britton, J. H.
Broadbent, J. F.
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Burns, J.
Chown, T. C.
Coleman, J. W.
Coleman, M. T.
Comeley, W. T.
Crockett, W. B.
Dawson, H.
Dunn, G. W.
Dutton, H. R.
Edey, L. F.
Elliot, W. R.
Ferguson, T.
Fielding, W. G.
Fraser, J.
Gardner, K. V.
Goodenough, A. J.
Guest, A.
Haight, H. V.
Hanson, L. J.
Harragin, H. C.
Harrison, J.
Hearn, J. H.
Hendry, J.
Holland, F. E.
Hopperton, L.
Hoyt, C. C.
Hughes, J. W.
Inns, G. A.
Jackson, J. R.
Jacques, A.
James, H. H.
Jeffries, G.
Kelly, E. J.
Lecavalier, A.
Linagh, R. K.
Loudon, A. C.
Mcnab, E. S. M.
Mathesons, A. G.
Milne, D.
Munro, J. D.
Murphy, E. J.
Mynard, T.
McCarthy, J.
McHattie, F. W.
McNown, W. L.
McLaughlin, G. P.
Naylor, H. R.
Noakes, R. J.
Nye, H. F.
Odell, C. A.
Ogden, J.
Palme, J. E.
Patterson, W. R.
Perrett, G. A.
Playfair, J.
Primeau, J. L.
Prevost, L. E.
Prouse, W.
Pugh, G. W.
Rake, H.
Redmond, W.
Reid, H. G.
Rennell, G. A.
Richardson, S.
Ross, J. D.
Seccombe, A. G.
Sheridan, W. P.
Shortley, B. F.
Sleigh, T.
Stanger, R.
Starkey, J. B.
Stott, W. A.
Stuart, H. B.
Symmes, F. H.
Taylor, J.
Thomas, E.
Tourville, M.
Towne, A. C.
Wheatley, G. H.
White, C.
Whitings, H. T.
Winslow, E. S.
Woollam, A. E.
Booth, W. A.
AND OTHERS

Chairman:

The minutes of last meeting have been distributed, and, as you are aware, the meeting tonight will be addressed by Mr. Wm. Carter, A.M., A.S.M.E. His paper is entitled "Some Elements of Economy in Air Compression," but before Mr. Carter commences, the Secretary will read the names of those who have lately been nominated for membership.

NEW MEMBERS

Cameron, H. S., Vice-President, The J.W. Cumming Manufacturing Co., Ltd., New Glasgow, N. S.
Cumming, J., President, The J. W. Cumming Manufacturing Co., Ltd., New Glasgow, N. S.
Daniels, A. G., Contract Foreman, Can. Pac. Rly, Angus Shops, Montreal.
Drummond, C. B., Manager, Can. Pilling Co., Montreal.
Elliott, W. R., Export Traffic Manager, Can. Ingersoll Rand Company, Montreal.
Gilson, T. W., Chief Engr., C.P.R., Angus Shops, Montreal, Q.
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Whitrod, W., Contract Foreman, C. P. Rly., Angus Shops, Montreal, P. Q.

Chairman:

I will now call upon Mr. Carter to come up to the platform, please.

Mr. W. Carter:

Gentlemen: The subject of the paper that I am giving you tonight is "Some Elements of Economy in Air Compression." The object of the paper is to place clearly before you

certain essentials and elements, to give you a clear understanding of what the Air Compressor is and should be. The slides I am going to use are simply to show you some of the various devices and designs used.

Second only to electricity in the extent and diversity of application, compressed air is one of the most important agents in every phase of the development of civilization. In the arts, sciences and manufactures, its use has wrought economies which could otherwise never have been realized. Compressed air appliances have exercised an influence upon improved standards of living, second to no other means of power transmission and application. Wherever properly applied, they have brought about economic results which are reflected in every field of activity. But the efficient application of compressed air presupposes an efficient source of compressed air. The most economical devices cannot work to advantage under a high cost of power.

The cost of compressed air, for whatever purpose or however produced, involves three separate items;—first, interest and depreciation on the investment for compressing equipment; second, cost of operation; third, cost of maintenance or up-keep. Extravagance in any one, will offset savings in the other two. Compressed air can be had at minimum cost only when each of these three items is minimized. All three depend fundamentally upon the design and construction of the air compressor.

An air compressor is a machine for transforming energy from one form to another, and is to be considered as primarily made up of three parts, namely, the driving element, the compressing element, and the mechanical structure, combining these two which may be designated as the power transmitting element. It is not always possible to draw the line sharply between these several elements, but the subdivision can be made with more or less exactness.

In the transformation of energy there is a certain loss. The measure of overall efficiency of an air compressor is the ratio of the horsepower applied as initial energy to the horsepower represented delivered. The inevitable losses in air compression may be broadly classed under five headings, as follows:

The first loss is that due to friction in the mechanical structure which transmits the power from the driving to the compressing element. The second loss is that arising from the

heating of the air during admission to the cylinder, resulting in a reduction of its density and a diminished volumetric effeciency of the cylinder. The third loss arises from the heating produced by compression and its effect upon the air during compression, calling for more power. The fourth loss comes from the reduced volumetric efficiency of the cylinder due to the fact that the intake air is seldom at atmospheric pressure owing to friction in the inlet valves and passages. The fifth loss is also one of volumetric efficiency due to the effect of the clearance air in reducing the effective length of the admission stroke.

These various losses can be kept down to the minimum by correct design, and construction, but they can never be entirely eliminated. It is not possible even to give average percentages for any one of these losses, which may occur in different combinations, depending upon the mechanical details, the general type, the speed and the capacity of the compressor. After all these losses have been deducted the net efficiency of the machine remains, and of this Mr. Frank Richards says, "It is safe to say that the ultimate efficiency never goes as high as 80 percent, while it often goes below 60 percent."

Taking up now, in order, the three primary parts into which the compressor has been divided, the driving element comes first for consideration. Air compressors can be broadly defined as either steam driven or power driven.

LANTERN SLIDES

The ordinary steam driven compressor is simply a steam engine with one or more air cylinders directly coupled on an extended piston rod. With this understanding it will be unnecessary here to enter into any detailed consideration of the design of the steam end. What constitutes good steam engine practice is the best compressor practice so far as the steam end of the compressor is concerned.

However, there is one vital distinction between steam engine and compressor practice. The steam engine for ordinary power purposes must maintain a constant speed irrespective of load. The steam driven air compressor, on the contrary, in order to maintain its output of air properly adjusted to its load, must run at a variable speed, for its piston displacement or its capacity is directly proportional to its speed. This means that while the steam engine has a variable load per stroke, the air compressor has a constant load per stroke, except for the small discrepancy due to varying friction and

compression efficiency at varying speeds .

This feature has no particular bearing upon the performance of air compressors with simple steam cylinders, but it has a most important bearing upon the application of compounded steam cylinders to compression work. The first essential of successful steam compounding is in maintaining the proper ratio of expansion. This means that for a given steam pressure, for a given back pressure and for a given cylinder ratio, there is one and only one proper point of cut-off for both steam cylinders.

In any given case the first and third conditions must be considered constant, leaving the second condition as the variable which is to be adjusted to meet varying conditions. Where a constant speed must be maintained regardless of load, this must be accomplished by change of cut-off; and in compounded steam cylinders this immediately destroys the proper ratios of compression, and sacrifices economy. Constant speed practice with compounded engines must be a compromise, even at the best.

But in the air compressor, where the load per stroke is constant, the cut-off on the steam cylinders, remains practically constant, and the correct ratio of expansion is maintained over the full load range. The word "practically" is here used advisedly, since there is bound to be a very slight departure from perfect conditions to produce the necessary change of speed under varying load. But it will be evident that the air compressor offers the ideal opportunity for securing in highest degree the advantages of steam compounding.

It would appear proper that in steam driven air compressors the first element of economy lies in using compounded steam cylinders, operating under pressure which will make the saving worth while. The peculiar operating conditions of the air compressor, just explained, justify compounded steam ends under pressures lower than would be advisable in ordinary engine practice. The largest builders of air compressors are recommending steam ends for as low as 80 pounds boiler pressure running condensing, and for 100 lbs. running non-condensing.

The three fundamental advantages of compounded steam cylinders on air compressors may be summarized as follows: Lower fuel consumption and fuel cost, lower cost of boiler feed water, lower cost of boiler plant and accessories.

In Canada, due to extensive Hydro electric developments, and electric power frequently becoming available after steam

driven compressors are installed, a large Canadian builder has adopted the standard of building all of their steam driven compressors with the air compressing cylinders located next to the frame so that the machine is readily convertible to a belt driven machine when power other than steam is available.

Turning now to the subject of power driven compressors, they are in general an evolution from steam driven types. They differ, however, from the others in the vital fact that while steam driven compressors are variable speed machines, power-driven compressors are in the vast majority of cases constant speed machines. This makes the problem of regulation quite distinct in the two cases. This point will be taken up more fully later on.

Discussing now the various methods of drive, belt drive is the most common and is always applicable either from line shaft on smaller sizes or by individual driving element using either electric motor or oil engine belted to suitable belt wheel. A good rule to follow for belt centres is the diameter of the driven pulley plus 8 to 10′. Where long belt centres cannot be had the short belt drive referred to later can be applied.

Rope drive is perhaps the next choice, although it is seldom used where the power to be transmitted is small. It is particularly advantageous in large sizes where short centres only can be had, as the grip of the rope in the grooves gives the necessary pulling power without undue tension and bearing friction. The durability and efficiency of the rope drive depend entirely upon the shape of the rope grooves and upon the use of a suitable number of ropes so that no one rope is under excessive strain.

The use of tighteners for rope is always to be avoided. A recent development by one of the larger builders, however, opens up large possibilities for belt drive on close centres without any increased friction. This arrangement involves the use of a floating idler pulley and a very slack belt. The weight of the idler takes up the slack of the belt and increases the arc of contact on the driving and driven pulleys so that the full power is transmitted without any undue strain on the bearings or on the belt itself.

Gear drive and silent chain drive are never desirable and should be used only where the demand for compactness renders them imperative. The best practice places the limit of power for gear drive with a raw hide pinion at 40 H.P.; for gear drive with a steel pinion at 60 H.P.; and for silent chain or herringbone gear drive at 50 H.P.

A very modern development is the direct-connected electric driven air compressor with the rotor of a synchronous motor mounted directly on the compressor shaft. This construction is not applicable to smaller units than about 700 cu. ft., 100 lbs pressure compressors, because the cost for D. C. synchronous motors of small power becomes excessive. On moderate and large sized machines, however, this design affords the very highest possible economy in power driven compressors. Recent improvements in air valve movements and in air cylinders design which permit much higher piston speeds than ever before were considered practical, have contributed to the success of the direct-connected compressor unit of this design. Unless the valve and port areas are very large, the compression efficiency is so greatly reduced at the customary speeds as to offset the advantages of compactness. The choice of a direct-connected motor driven air compressor therefore, should be determined by an investigation as to whether the compressor had been specially designed for this method of drive.

The same general remarks apply to the direct-connected water wheel compressor. But as this style of drive is comparatively rare and can be used only where the head and volume of water are exactly right, this condition is not likely to come within the experience of the average engineer.

The extensive use of compressed air for operating tools and other equipment by compressed air has created a demand for a new design of air compressors, that is, the portable type of machine, and the development of a complete line of these machines has been undertaken. They can be gasoline engine driven, self propelled, for operating on standard guage railway track or gasoline engine driven or motor driven portable units. In ranges of capacity these machines are available in 100, 150 and 200 cubic feet units.

The problems encountered in a steam cylinder of an air compressor are problems of expansion. Coming now to a discussion of the second element in the air compressor—the compressing element—we find here that the problems are those of compression, almost an exact reverse of those in the steam end. In compressing air all of the energy applied is converted into heat. At first glance, therefore, economical considerations would seem to indicate that this heat should be retained during compression. As a matter of fact, however, economical air compression depends primarily upon the thoroughness with which the heat of compression is removed as fast as it is produced. Compressor practice uses one or both of two methods

for accomplishing this, namely, water jacketing, and compounding or stage compression.

If the piston of a compressing cylinder could move so slowly that the water in the jacket could absorb and carry off all the heat, it is evident that this jacketing process would save all the work which is represented on the indicator diagram by the areas between the actual compression line and the isothermal curve. But in actual practice a compressor cannot be run so slowly, and water jacketing is only a partial solution of the cooling problem.

Temperatures increase with the pressure in the cylinder, and it is evident that the advancing piston steadily reduces the effective area of jacket. Near the end of the stroke, when pressure and temperature are highest, very little of the cylinder wall is exposed, and the greater part of the cooling area remaining is the cylinder head. This emphasizes the importance of head jacketing and the superiority of those constructions in which the air valves are not in the heads, thus affording the largest percentage of cool head areas.

But even under the best conditions, water jacketing realizes only a part of the saving which its theory promises. Some beneficial effect in this respect it certainly has, particularly in slow speed, long-stroke machines. But probably its greatest value lies in its effect upon the lubrication and the resultant wearing qualities of the machine. Compression at sea level and ordinary atmospheric temperature to only 75 lbs. gage produces a temperature of about 400 degrees Fahr. If some means were not employed to reduce this temperature, the inevitable result would be the destruction of all ordinary lubricants and packings, and the rapid wear of piston rings, cylinders, rods and valves with extravagant leakage, loss of capacity, increased friction and excessive power consumption. But the water jacket keeps all parts reasonably cool and results in tight joints, free lubrication, little wear, reduced friction, easy running, and sustained capacity and efficiency.

It would seem advisable at this point to make some mention of the lubrication of air compressors as it has been found that not sufficient attention is given to this subject and the author will only touch on the subject briefly, and dealing only with the lubrication of the air cylinders of the air compressing element. For average normal conditions, the oil should be a medium bodied mineral oil of the highest quality, not compounded with fixed oils such as animal or vegetable, and should be carefully filtered in the final process of manufacture.

The quantity of lubricating oil to feed to the air cylinders of compressors, cannot be stated in exact terms due to the varying viscosity of different oils, the heat of compression and the size of cylinder. It may be stated in general, however, that after the cylinders have acquired smooth and polished surfaces, the quantity should be reduced to the lowest limit to avoid the possibility of accumulation of carbon and sooty deposits within the system due to excessive use.

It is perhaps unnecessary to say that it is almost as important that air should be admitted into the cylinder cool, as that it should be kept cool during compression. If a water jacket were not uesd, the entering air would be heated while passing through the hot valves and ports and by contact with the heated interior of the cylinder. This would mean the rarification of the intake air, reduced cylinder capacity, lower efficieney of compression and excessive terminal temperature. Since jacketing is at the best only partially effective, this latter argument suggests the advantage of those constructions which admit air through one, or at least only a few, large openings where only the outer film of the air is heated rather than through a number of smaller openings through which the air is finely sub-divided and heated.

The second process of cooling—compression in stages—is analagous to an arrangement in which the compressing piston of a single cylinder is stopped at intervals through its stroke and the partially compressed and heated air is withdrawn and cooled by some external means to its initial temperature or even lower; then returned to the cylinder to be further compressed, heated and cooled, until the desired pressure is reached. It is evident that such an arrangement would maintain a fairly uniform low temperature in the air volume throughout the stroke, giving very close to isothermal compression.

Such a proceeding is evidently not practical. But the same results may be obtained by compressing in several cylinders, in the first of which moderate pressure and temperature are reached and the air in this condition discharged through a cooling device which restores its initial temperature; then admitted to another cylinder for further compression and heating; again withdrawn and cooled and again compressed. This is a stage or compound compression. An average of the practice of the leading builders permits single stage compression for pressures up to 70 pounds or under some conditions to 100 pounds; two stage compression for pressures of 75 to 500 lbs.; three or four stage (preferably in duplex compres-

sors) for pressures of 500 to 1,500 lbs., and four stage compression for pressures from 1,500 lbs. up.

A three stage straight line machine should only be used for small or moderate capacities. Above this, the duplex type should be preferred because of its balanced construction and of the readiness with which it is compounded.

The primary object of compound compression is a saving of the power required by what may be called the heat element in compression. The degree to which this is accomplished depends entirely upon the efficiency of the intercooler. The ideal intercooler would be one which would reduce the temperature of the air to the temperature of the cooling water. This probably cannot be realized, but a good practical standard demands that the intercooler shall deliver air at a temperature not more than 10 degrees above that of the cooling water.

The successful intercooler involves six fundamental requirements. It must provide for a complete and minute subdivision of the air passing through it, that the heat may be dissipated without any dependence upon the best conducting qualities of the air itself. The air should be split up into thin sheets or streams so as to dissipate its internal heat. There must be an ample cooling surface presented to this subdivided air stream. The circulation of the cooling water must be properly directed in relation to the flow of the air, and its velocity must be such that the maximum amount of heat will be carried away without waste of water. All air passages must have ample cross section, that the velocity of air may be such as to give a length of contact with the cooling surfaces sufficient for the complete removal of the heat. Expansion and contraction must be provided for that there will not be a leakage of air or if water.

Compound air compression has important bearings upon other features of compression economy. It reduces the average structural stresses, resulting in a higher factor of safety and a longer life for the machine with a given weight of metal. The maximum stresses encountered in compression in two stages are only 55 or 60 percent of what they are in single stage compression to the same pressure. The reduction of stresses here referred to is felt not only in the machine structure but in the air valves, which show a notably easy operation under compound conditions. Another advantage of compound compression is an improved steam economy if the compressor is steam driven. The averaging of the stresses throughout the stroke, permits the work to be done, with a low-

er M.E.P. in the steam cylinder, which means a shorter cut-off and a greater steam economy. The reduced terminal stresses permit a higher piston speed with safety, thus improving the steam economy by reducing condensation losses and leakage in the steam cylinder.

High volumetric efficiency results from compound compression, coming from three sources. The first of these is the fact that the clearance pressure in the intake cylinder is lower. The second is a lower maximum temperature in the cylinders so that the entering air is not so much heated. The third is a reduction of leakage consequent upon the reduced extremes of pressure in each cylinder. Compound compression results in more efficient lubrication of the machine because of the lower temperatures involved. This means easier running, improved mechanical efficiency, less wear, lower repair costs, reduced leakage losses, and longer life. Compression in stages results in the delivery of drier air—a feature of great importance where the air is used under conditions which may result in freezing up of the exhaust ports. This also largely obviates the accumulation of water in pipe lines.

The air valves of a compressor are probably the most vital parts of a machine. While the number of different types of air valves is greater than the number of compressor builders, yet they may be broadly classified in two groups. Mechanically actuated valves have a positive motion derived through some mechanical connection from the rotating or reciprocating parts of the compressor. Poppet or automatic valves are operated wholly by differences of pressure. There are other designs of air valves in use to-day which cannot be exactly placed in either class but these need not be considered at this time as they generally are applied for special purposes and in special cases.

Without going into a detailed discussion of the many different types of air inlet valves, some general observations may be made as to their function and requirements. The function of an inlet valve is to admit the maximum volume of cool, clean air to the cylinder, with the least expenditure of power; to keep this air in; and to continue to perform this duty indefinitely at the least total cost. Analysis of this function reveals the following requirements of the successful inlet valve.

It must admit a volume of air which will entirely fill the cylinder, this air being as nearly as possible at atmospheric pressure. This calls for an instantaneous and complete opening of the valve, so timed that there shall be no escape of the

compressed air in the clearance space. This full opening should be held to the end of the stroke, and short, direct and unobstructed passages should be provided through ports and valves.

It must admit clean air, suggesting a design permitting ready connection to an intake passage or conduit leading to a place free from dust and grit. The air admitted must be as cool as possible—a condition partially met by the consideration just mentioned by which cool air as well as clean air should be supplied. But, more than this, the cool air supplied should nowhere be heated in its course into the cylinder, suggesting that valves, ports and passages shall be so placed as to be cooled by the cylinder jacket.

All the air admitted must be kept in the cylinder, calling for instantaneous and complete closing of the valve at the end of the stroke, with a perfect seating and without any leakage. All the processes outlined here must be carried on with the least possible expenditure of power for the overcoming of friction and the manipulation of the valve gear—a requisite demanding nice adjustment, simplicity of mechanism, perfect lubrication and as few wearing surfaces as possible. This exacting performance must be continued indefinitely, twice each revolution and hundreds of times per minute without undue wear or loss of adjustment. This condition is fundamentally one of correct design, high class materials and workmanship and generous lubrication.

The ideal inlet valve is here outlined. Probably no compressor valve on the market to-day exactly fulfils all these conditions; but many types represent the experienced judgment of the builders applied in an excellent compromise.

The functions of an air discharge valve are to release the full volume of compressed air from the cylinder with the least friction and power expenditure; to keep it all out after discharge, and to continue indefinitely to maintain this duty without undue expense. The primary essentials of such a valve are as follows:

Its opening must be full and instantaneous, must occur just at the right point in the stroke and must be held open until the piston comes to rest. The valve opening must be ample so that the velocity of discharge may not be excessive and the ports and discharge passages should be short and free from obstruction, to reduce friction.

As few parts as possible, and these correctly adjusted, should provide for the necessary valve movement with the minimum loss of power in mechanical friction.

The valve should close instantly and completely as soon as the piston stops, that there may be no return of the air discharged when the piston starts on its back stroke. Such a return of compressed air would have the effect of an increased clearance, reducing the capacity of the cylinder.

The continued maintenance of this performance (which is more arduous upon the discharge valves than upon the inlet valves because of the higher pressure) suggests the advisability of a simple construction with the fewest bearings, careful workmanship, the use of good materials, perfect lubrication and careful distribution of materials. It is always to be remembered that discharge valves and ports are continually exposed to a flow of heated air even where jacketing is most complete. On the other hand, an essential of inlet valves and ports is that they shall be kept cool. The latter should therefore be removed as far as possible from the former, nor should the same ports be used for both inlet and outlet.

It might, at first glance, seem that the area of the discharge valves, ports and passages could be much less than the corresponding inlet area, since the former must pass the air at a higher pressure and in less volume than the latter. But it is to be remembered that while the inlet areas are open during the full stroke, the discharge areas are open for only a part of the stroke—about one-third. In order, therefore, to make the velocity of discharge about the same as that of intake or admission, it is usual to make the inlet and discharge areas approximately equal.

It is important that the velocity of flow through the valves, ports and passages shall not be excessive, and this depends upon the piston speed which is a widely variable quantity. The higher the piston speed, the larger should be the area. In actual practice, the inlet areas vary from 3 to 15 percent of the cylinder areas, with an average probably around 9 to 10 percent. The corresponding discharge areas from 7 to 15 percent, with an average in the neighborhood of 10 to 12 percent. The larger these areas, the better the economy. The modern design, the lightness of weight of plate and strip type of valves permit higher velocities than was formerly considered good practice. This is owing to the small differences in pressure required to open the valve and concentration of engineering talent in the correct shape and design in the

ports through the air valve to give the least resistance to the air flow.

Owing to the increased friction through a number of small passages as compared with that through a single large one, the actual measured area in the former case should be 50 to 100 percent larger than the latter. This explains why the measured inlet area of machines with Corliss or other large area inlet valves is often so much less than the measured discharge area of many small poppet discharge valves, while still giving good results.

It may be well to recall at this point that cylinder clearance is really made up of three elements; the inlet port clearance, which is all the space left between the closed inlet valves and the inner surface of the cylinder, the discharge port clearance, which is the corresponding space in the discharge passage, and the piston clearance, which is the space allowed for safety between piston and cylinder head at the end of the stroke. This latter element is an essential in compressors. But it is not unusual for the other two elements together to constitute by far the larger proportion of the total clearance. This suggests the superiority of those valve designs in which inlet and discharge port clearance are reduced to the lowest practical limit.

Coming now to consideration of the third element in air compression, the mechanical structure, we find that it has a very important bearing upon the economy and the endurance of the machine.

The mechanical efficiency of a compressor can be exactly determined by a comparison of the steam and air indicator cards, (in a steam driven machine) or by a comparison of the measured power applied to the horsepower of the air indicator card (in a power driven machine). The difference between these values represents the power consumed in the friction of the compressor. Good mechanical efficiency, therefore, depends upon the extent to which friction is reduced. There is no time here to enter into the details of compressor design, it will be enough to enumerate some points having a vital bearing on this subject.

Power should be applied to resistance—steam pressure to air pressure—in as direct a manner as possible, so that bending or deflecting strains may be avoided as far as possible, with the resultant binding of bearings and loss of correct alignment.

Ample metal should be used, properly disposed to afford the rigidity necessary as a further precaution against the attendant binding stresses, just mentioned. A light construction is always to be avoided.

Lest this correct proportioning of metals to meet stresses should result in an excessive weight and an extravagant cost, these metals should be of the best quality and intelligently selected for specific purposes, affording the maximum strength per unit of weight.

All bearings should be of ample area, so proportioned as to give a safe, moderate pressure per inch of bearing surface.

Wherever possible bearings should be supplied with removable linings (preferably of anti-friction metal). In all cases, whether thus lined or otherwise, they should be scraped smooth and true, properly adjusted and arranged for the ready distribution of lubricant—all of this tending toward a lower co-efficient of friction for these bearing surfaces.

Complete provision should be made for a plentiful supply of lubricant to all bearing surfaces, furnished preferably by an automatic system which will be efficient at all speeds.

The utmost simplicity should be sought throughout, reducing the number of parts, the number of joints, (each an element of weakness) and the number of bearings, with their attendant friction and their possible loss of economical adjustment.

The design should afford a ready accessibility at every point, inviting frequent and careful attention to the maintaining of a correct adjustment of all parts for most efficient operation.

Steam compounding and compound air compression have important effects upon the mechanical efficiency, which have already been discussed in the proper place.

Friction has been aptly defined as "that portion of the power consumed by a machine in wearing itself out." This definition throws on the question of compressor endurance a light in which the importance of a high mechanical efficiency appears in bold relief. True economy is a question, not of momentary results, but of results covering months and years of continuous service under all conditions; and a compressor in which the percentage of "wearing out power is least," promises not only the highest, but also the longest record of sustained economy and satisfactory service.

While the regulating devices or governors used on air compressors vary in detail among the different builders, all

may be divided, as far as the principle of operation is concerned, into two classes.

The first class is that applied to compressors with plain or adjustable cut-off valves of flat or piston type. It operates by throttling the steam supply as load diminishes. Devices in this class consist fundamentally of a valve in the steam pipe, which is opened or closed by action of a piston in a cylinder, this piston being actuated by air pressure from the receiver. The movement of this piston is opposed by weights on a lever or by a spring, and the spring tension or the weights may be adjusted so that the governor valve is full open at any desired normal air pressure. But when pressure exceeds this limit, the tension of weight is overcome, and the valve in the steam supply is closed in a degree corresponding with the amount of excess pressure. This slows down the machine and reduces the volume of air discharged until such time as the normal pressure is reached, when the weights or spring tension again open the governor valve, and full speed is restored.

The second class includes governors applied to machines with Corliss steam valves. The mechanism consists of a pressure cylinder and piston with opposing weights or springs as described in the preceding paragraph, but in this case the movement of the governor, instead of throttling the steam, changes the cut-off of the steam valves, reducing speed under partial load, and restoring it as load increases. The resistance per stroke being the same throughout, a very slight change of cut-off hardly effecting the economy, produces all the speed change necessary.

Both of these classes of governors include also a speed-limiting device, the more common form being the familiar fly-ball arrangement, which throttles the steam supply or greatly shortens, the cut-off when speed exceeds a certain limit, as it might in case an air pipe should break or other accident occur.

There are occasional instances in which governors of one or other of the above classes are used in connection with an unloader on the air end, so arranged that, as the speed falls off, the load is partially taken from the air end. These are the specialties of individual builders, and as such cannot be elaborated upon here. The two general classes defined cover the general requirements of this paper.

Since the power driven compressor is almost always a constant speed machine, the methods of regulation and govern-

ing described for variable speed steam driven machines evidently cannot here be applied. Constant speed means constant piston displacement, and the problem of delivering a variable volume of air with constant piston displacement, becomes one of making a portion of that displacement non-effective in the compression and delivery of air. Only the fundamental principles of several methods of accomplishing this will here be discussed.

The first method is really one of unloading, rather than of regulating. A pressure controlled mechanism is arranged so that when pressure exceeds normal, due to excess of delivered volume over demand, a communication is opened between the two sides of the compressing piston. Usually this is accomplished by opening and holding open one or several of the discharge valves at both ends of the cylinder, the air then simply sweeping back and forth from one side of the piston to the other through the open valves and the air discharge passage. When normal pressure is restored, the valves are automatically closed, and compression and delivery are resumed. Evidently this is practically a total unloading of the machine for a longer or shorter period—a sudden release from load and a sudden resumption of load. Moreover, the air which is swept back and forth by the piston in its travel is air under full pressure, so that when the discharge valves suddenly close, the piston at once encounters a full cylinder of air at maximum pressure. These facts limit regulators of this class to machines of comparatively small capacity.

Another method provides by means of a pressure operated device for the total closing of the compressor intake under reduced demand. This form of unloading consists of a double disc valve on the intake of the compressor which closes completely when the desired air pressure is reached and prevents any more air being drawn into the cylinder. Owing to its construction it is always wide open or entirely closed, the movement of the valve being complete and quick so that there is no wire drawing or throttling of the incoming air. The operating device or auxiliary valve controlling this form of unloader is governed by means of a needle valve or separate auxiliary operating valve either of which operate when the desired air pressure is reached for which these valves are set.

When compressors are operated unloaded for long periods without resuming their load, the addition of a cylinder relief valve can be applied to keep down excessive temperatures. When these relief valves are applied they are operated simul-

taneously with the closing of the intake unloader. Their use permits entirely unloading the air cylinder by opening each end to the atmosphere. The use of cylinder relief valves is more particularly beneficial on straight line compression and where the ratios of compression are high.

A further modification of the use of the intake unloader has been developed by one of the large builders using the intake unloader in combination with a discharge line unloader for two stage compression. The discharge line unloader is never used alone but only in connection with the intake unloader when it is desired to attain the greatest possible reduction in horsepower during unloading periods. It is connected directly to the discharge opening on the high pressure cylinder in such a manner that the flow of air through the device from the cylinder is to the atmosphere. The operation is instantaneous, opening a passage directly from the high pressure cylinder discharge passage to the atmosphere when unloaded. This is accomplished by opening a pressure operated valve which is controlled by the same auxiliary valve as controls the intake unloader. When the pressure operated valve is opened communication between the discharge passage from the high pressure cylinder is direct to the atmosphere and the air in the pipe line and receiver are held back by an automatic closing check valve. On the resumption of demand, the intake unloader opens and simultaneously the pressure operated valve in the discharge line unloader closes and the air is passed on to the receiver.

The third method is very similar to the first except that here the inlet valves instead of the discharge valves are held open when the machine is unloaded and in single stage machines the piston simply draws in and forces the air out to atmosphere. In the case of two stage compression some or all of the inlet valves at each end of both the high and low pressure cylinders are held open. In the case of the low pressure cylinder the air is exhausted through the suction passage back of the atmosphere and the cool clean air is sent back and forth into the low pressure cylinder after the first air is exhausted. In the case of the high pressure cylinder the air is exhausted back into the intercooler and the piston sweeps back and forth in a balanced condition. This system of regulation can be applied in two steps on two stage compressors so that half of the low pressure cylinder and half of the high pressure cylinder can be cut out at a given pressure and the second half of the low pressure cylinder and the sec-

ond half of the high pressure cylinder can be cut out at a slightly increased pressure. This form of regulating gives a regulation on the basis of "no load," 50% load and "full load." In this system of regulating, when the pressure drops to a pre-determined point the valves are automatically closed and compression of delivery resumed. This form of regulating and unloading is applicable to single stage compressors and to two stage compressors. It is also possible to use this form of regulation on steam driven compressors of the straight line type in combination with combined speed and pressure governors, where separate controlling or operating valve is used, which first acts on the steam governor slowing the machine down to a pre-determined number of revolutions per minute, after which the free air unloader will come into action and fully unload the machine. In the loading condition the free air unloader is first closed with a further drop of pressure the governor brings the compressor up to its rated speed.

The most superior method of regulation known to compressed air engineers and usually employed on two stage compressors above 1000 cu. ft., provides auxiliary clearance spaces or pockets at each end of the cylinder which successively cut in as the load diminishes. The excess air is simply compressed into these clearance spaces and expanded on the back stroke. The capacity of the cylinder is reduced without any appreciable waste of power, for the energy used in compressing the clearance air is given back by its own expansion. A big advantage of this type of unloading is that it is the only known method of unloading a two stage compressor of two cylinders in four definite steps and still maintain both sides of the machine in balance. This is a particularly desirable feature on larger compressors where it is usual to employ direct connected synchronous motors. It might be said that a four step definite unloading can be accomplished with the free air unloader by using two low pressure and two high pressure cylinders.

In the clearance control method of unloading the practice is to have two clearance pocket control valves at each end of each cylinder which are controlled by an auxiliary valve. The accomplishment of four step unloading is caused by the auxiliary valve first opening up one valve on one end of the low pressure cylinder together with one valve on one high pressure cylinder at the same moment. This gives three-quarter capacity. A slight increase in the air pressure causes the auxiliary valve to open up one clearance control pocket

in the opposite end of the low pressure cylinder together with reciprocal pockets at the opposite end of the high pressure cylinder.

A further increase in pressure operates the third stage bringing the load down to a quarter by means of opening up a second clearance valve on the low and high pressure cylinders on the same end on which the first stage was accomplished. A still further increase puts the compressor into fully unloaded condition by opening up the last clearance pockets which are located on the same end that accomplished the second stage or half load condition. As the demand for air increases the load comes on in steps in the reverse order.

In the odd cases where it is found advantageous to operate the compressor by means of automatic start and stop control electrical devices, special means must be taken to insure the compressor is unloaded when starting up from a position of rest with pressure in the air receiver. There are several methods of accomplishing this, and we shall only attempt to describe two or three of these.

One is by means of an electrical solenoid operating valve. This is somewhat of an expensive apparatus. Compressed air engineers have developed an entirely mechanical method which is cheaper than the solenoid method, which is operated by means of pilot valves attached to the indicator openings which operate a specially designed discharge line unloader. These operating valves are controlled by a peculiar air action in the cylinder at the moment the machine comes to rest and do not permit the discharge line unloader to allow the air to be pumped into the receiver until the compressor is up to speed.

On small vertical compressors which are very frequently used with automatic start and stop control a very simple device has been designed which operates by means of centrifugal action. The weights of the centrifugal unloader are attached to the end of the crank shaft and when the compressor comes to rest these weights control the operating rod which holds the inlet valve open. When the compressor is up to speed the inlet valve resumes its usual function.

On power driven compressors with Corliss intake valves, several different methods of unloading or regulating are used.

By one method the Corliss valve is held open for the full admission stroke, and also a part of the compression stroke, this latter portion being determined by the unloading called for. Evidently this is practically equivalent to a shortening of the stroke of the compressor.

By another method the Corliss intake valve is opened full at beginning of admission, but closes later in the admission stroke. The air admitted to that point is expanded or rarefied for the remainder of the compression stroke, and then compressed, the volume of compressed air delivered being of course reduced. This arrangement is productive of an excessive temperature range in the cylinder. Still a third method opens and holds open the intake valves at the end of the cylinder, or at opposite ends in duplex machines. The effect of this is to make ineffective one out of every two strokes If still further unloading is necessary, the intake valves at the other end of the cylinders or cylinder are opened and held open. The three arrangements just outlined all operate by a pressure controlled mechanism which actuates some form of trip on the Corliss air valve gear, somewhat similar to the release mechanism of the Corliss steam valve for varying the cut-off.

Three things are to be avoided in the successful unloader or regulator for power driven machines, first, a sudden release or resumption of load, throwing heavy strains on the machine; second, undue rarification of the intake air, resulting in a wide range of cylinder pressures and temperatures; third, the blowing off of compressed air to the atmosphere with a waste of power.

In the regulation of the power driven compressor, less reliance must be placed upon the automatic regulation of the individual machine than upon the intelligent subdivision of the load between two or more machines and upon the careful management of the resulting plant. In designing a plant of these machines, maximum capacity must be cared for in the normal output of the machines, while partial loads are provided for by starting or stopping one or more marhines, the remainder running at or very near full yload. It is usually desirable to start a power driven compressor with no load, throwing on the load gradually after normal speed has been reached. This is, in fact, essential in machines driven by electric motors, for the heavy inrush of current in starting under load is dangerous, particularly where power is taken from a transmission circuit supplying other motors.

Evidently almost any of the unloading devices noted in the previous section can be used for this purpose if properly arranged for manipulation. The usual form, however, is simply a by-pass valve to atmosphere on the line close to the compressor protected by a check valve between it and the re-

ceiver to prevent the return of air from the line when the starting unloader valve is open. This check valve is essential where several compressors serve one line, permitting cutting in or out any machine without unloading the others. This by-pass valve is open on starting, when the compressor simply compresses to a pressure sufficient to open its discharge valves, this air escaping to atmosphere. When normal speed is reached, the by-pass or unloading valve is gradually closed and load resumed. On two stage machines, an unloader valve should be provided on the low pressure discharge of the intercooler, as well as on the high pressure discharge to the line. In the latter case, both cylinders operate momentarily as low pressure cylinders.

Mr. G. M. Wilson:

Now, gentlemen, you have heard the reading of Mr. Carter's paper, and I daresay you have marked some places in it as he went along. I have no doubt you have some questions that you would like answered, and I am sure Mr. Carter stands ready to do so.

Mr. G. W. Dunn:

I would like to ask Mr. Carter how he unloads a single acting machine by holding open the discharge valves?

Mr. W. Carter:

Single acting machines are not usually unloaded in this manner, and this method of circulation applies only to double acting machines where the compression piston cannot be balanced by the communication through the discharge passage being fully open.

Mr. G. M. Wilson:

Mr. Carter laid considerable stress on the air being kept cool, which is accomplished by means of two or more stages of compression, also the introduction of the intercooler. I would like to ask him his opinion of an aftercooler. Is it an economy?

Mr. Wm. Carter:

The aftercooler does not enter into the "Elements of Economy in Air Compression," the function of an aftercooler is primarily to reduce moisture after compression, and in all plants of capacities of 500 cu. ft. and over, where the terminal pressure is above 70 lbs, it is very desirable to use aftercoolers, as considerable moisture can be eliminated by its use. There are several forms of aftercoolers, but the most efficient is type using water as the cooling medium,

passing the water through tubes and the air around the tubes in thinly divided streams. The aftercooler should be placed as close to the compressor as possible, preferably between the compressor and the Air Receiver, and should be drained at frequent intervals. The decided advantage of using the aftercooler in taking the moisture out of the air at this point, means that tools and appliances using air will be properly lubricated, as otherwise, the moisture carried in the air will wash out a great deal of the lubricant.

Mr. G. M. Wilson:

In the use of an aftercooler is it desirable to have a trap of some kind?

Mr. Wm. Carter:

A trap can be used to drain the water from an aftercooler, but they are not usually installed, because depending on an automatic device to drain the moisture, sometimes makes the operation careless, and if the moisture was allowed to accumulate, it would be carried over a much larger volume to the Air distributing system.

Mr. F. Atkinson:

Why do some builders use two types of valves on Tandem Compound straight line Compressors?

Mr. Wm. Carter:

I do not intend, Mr. Chairman, to undertake the discussion of designing, but since the question has been brought up, it is purely the matter of a manufacturer's choice of valves to obtain proper valve area.

Mr. G. M. Wilson:

Did I understand Mr. Carter to say, when an Unloader comes into action the compressor maintains uniform speed, or does it slow down?

Mr. Wm. Carter:

With power driven machines either with belt drive or with direct connected motors the unloading systems applied to these compressors simply act to take the load off compressing cylinders and speed is maintained uniformly. To the contrary on steam driven machines, the speed is varied in accordance with the load, in the case of straight line steam driven machines the speed generally reduces only to a point that the machine will continue to turn over, and the load on the compressing cylinder is then relieved in

the case of duplex steam driven machines with crank set at right angles, machines can vary their load from rest to full speed.

Mr. H. R. Naylor:

Is it always economical to centralize. Where there are many miles of pipe is it economical to place an air compressor in an individual shop in order to get away from pipe line friction and so forth?

Mr. Wm. Carter:

There are a great many conditions covering the question as to whether it is more economical to centralize a compressor plant or install individual compressors at outlying points as outlined in the paper in designing a plant maximum capacity must be considered, and if the air lines are properly proportioned, centralizing is the better proposition, since it places a larger number of compressors under the operation of one engineer; unfortunately, most plants start with a small compressor and small pipe lines, and when the compressor plant is increased, the pipe lines are not usually enlarged. If this case exists, sometimes abnormal friction losses are encountered in the pipelines, and it is a question of cost whether the pipelines should be renewed or compressor installed at some point where there is more air required; each individual case has its own merits and its own study.

Mr. W. A. Booth:

Mr. Chairman, may I take this opportunity of extending to Mr. Carter, through you, a very hearty vote of thanks. I know Mr. Carter has worked very very hard on this paper, and can say that it is one of the finest papers we have ever had presented.

Mr. G. M. Wilson:

Will some gentleman kindly second that vote of thanks. Moved by Mr. Booth and seconded by Mr. Dunn that a vote of thanks be given Mr. Carter for the very splendid paper he has presented tonight. The subject for the next meeting will be "Some Recent Developments in Locomotive Construction," also moving pictures of what is known as the "Prosperity Special," by Mr. Grafton Greenough, Vice-President of the Baldwin Locomotive Works. I surely appreciate the attendance here tonight notwithstanding the inclement weather, and I thank you very much for your kind

attention tonight to the speaker. Our Secretary has provided some light refreshments of which you are invited to partake, these will be served in an adjoining room.

Mr. Wm. Carter:

I would like to say that it was with a great deal of pleasure that I prepared such a paper for the Railway Club. I did it with a whole heart, and feel very gratified at the vote of thanks that has been given.

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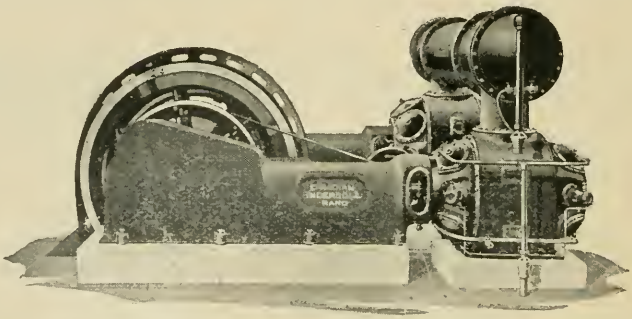

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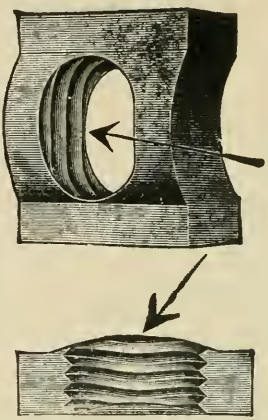

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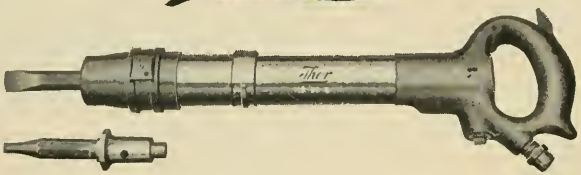

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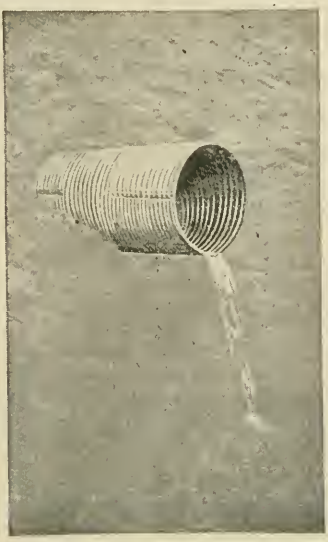

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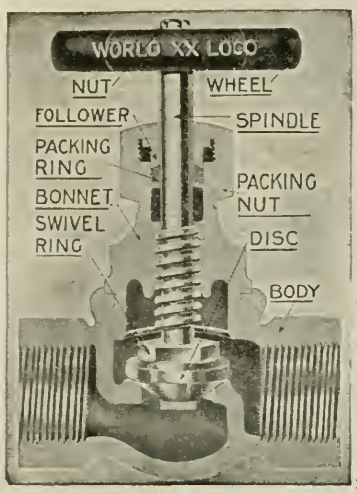

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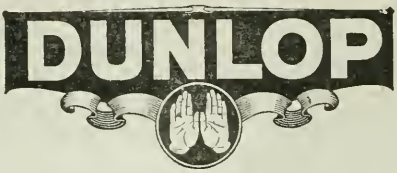

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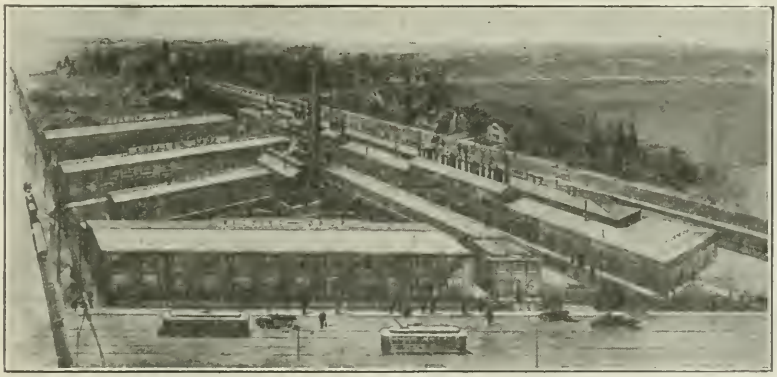

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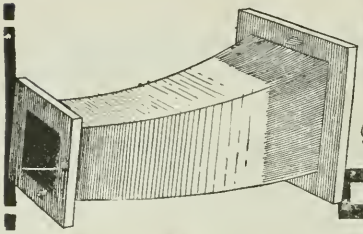

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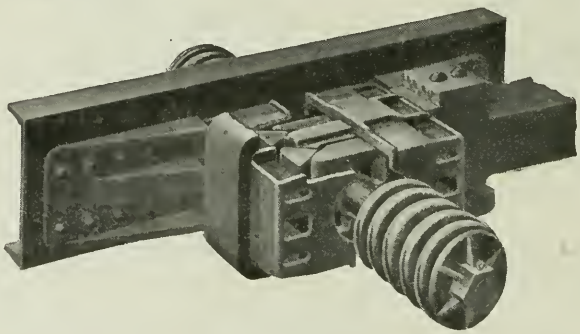

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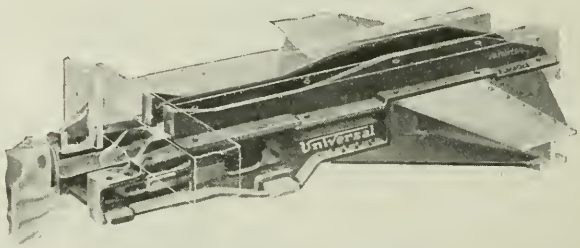

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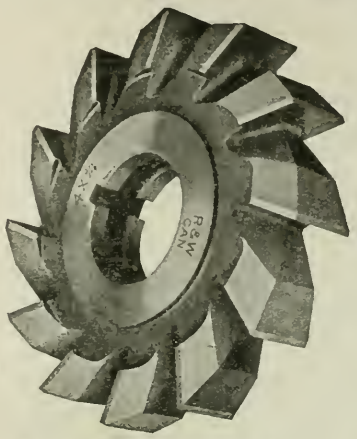

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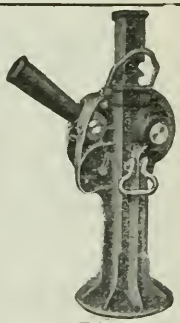

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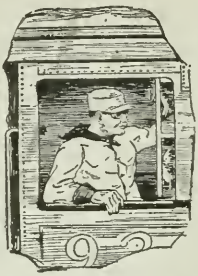

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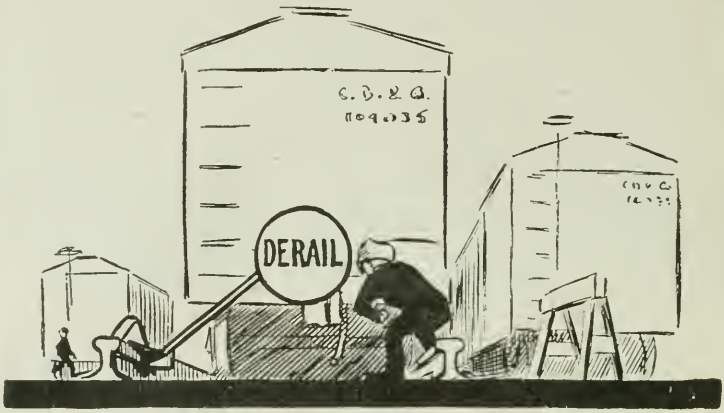

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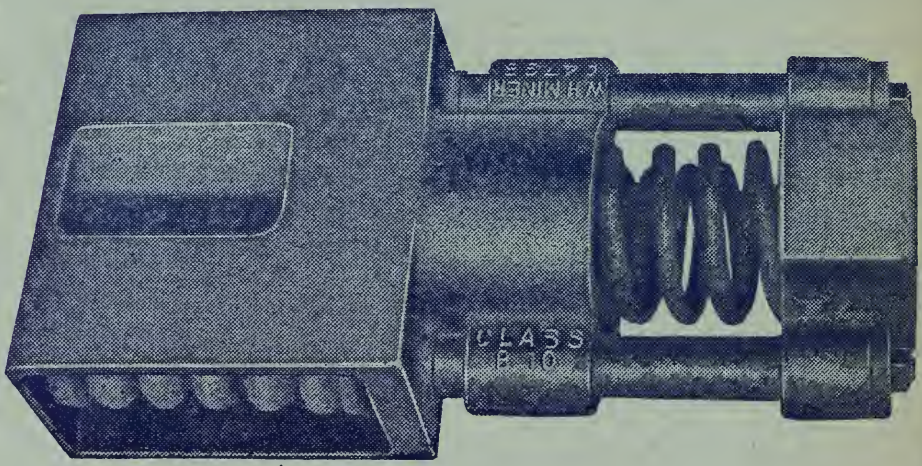

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